ELSEVIER

Journal of Alloys and Compounds 451 (2008) 473–476

Journal of ALLOYS AND COMPOUN

www.elsevier.com/locate/jallc

Relaxation rates of magnetization in $LiYF_4:Ho^{3+}$ crystals

B.Z. Malkin [a,*], M.V. Vanyunin [a], B. Barbara [b], S. Bertaina [b,c]

[a] *Kazan State University, Kazan 420008, Russian Federation*
[b] *Laboratoire de Magnétisme Louis Néel, CNRS, Grenoble 38042, France*
[c] *Ecole Nationale Supérieure de Physique de Grenoble, 38402 St-Martin d'Hères, France*

Available online 19 April 2007

Abstract

Theory of magnetization relaxation in a diluted paramagnet based on calculations of relaxation rates due to electron–phonon coupling a magnetic dipole–dipole interactions is developed. Assuming fast establishment of equilibrium in the spin system and the Gaussian line shape the spectral density of the dipole–dipole reservoir, we have derived a master equation for a paramagnetic ion. The developed approach is used interpret dynamic magnetic measurements in $LiYF_4:Ho^{3+}$ single crystals. We show specific variations of low temperature magnetization dynam at the magnetic field values corresponding to (anti-)crossings of electron-nuclear sublevels of the Ho^{3+} ground state. The measured dependenc of the ac-susceptibility on frequency, holmium concentration and the applied magnetic field are described when taking into account the phon bottleneck effect and the cross-relaxation. Evolution of the magnetization of the $LiYF_4:Ho^{3+}$ in the reversed field is considered.

Keywords: Rare earth alloys and compounds; Electron–phonon interactions; Spin dynamics

1. Introduction

Measurements of dynamic susceptibility [1], magnetization hysteresis in sweeping magnetic fields [2], and ^{19}F nuclear relaxation rates [3] in diluted paramagnets $LiYF_4:Ho^{3+}$ have revealed specific variations of the magnetization dynamics at the magnetic field values corresponding to crossings/anti-crossings of the electron-nuclear sublevels of the ground doublet state of Ho^{3+} ions in the crystal field of S_4 point symmetry. Results of these experimental investigations gave evidence for considerable changes (by orders of magnitude) of relaxation rates in the electron-nuclear system at the energy level (anti-)crossings. The goal of the present study is to clear up specific features of the dynamic susceptibility at liquid helium temperatures and the magnetization dynamics in sweeping magnetic fields. Different phenomena caused by the electron–phonon, magnetic dipole and hyperfine interactions are considered.

2. Kinetic equations for diluted paramagnets

The equation of motion for the density matrix $\rho(t)$ of a paramagnetic ion coupled to a phonon bath in the external magnetic field in the basis of eigenfunctions of the Hamiltonian $H_0 + H_1$ (with eigenvalues E_n) of an electronic (or electron-nuclear) system can be written as follows [4]:

$$\frac{\partial \rho_n}{\partial t} = \sum_k W_{nk}^{\mathrm{SL}} \rho_k, \qquad \frac{\partial \rho_{nk}}{\partial t} = -(\gamma_{nk} + \mathrm{i}\omega_{nk})\rho_{nk} \quad (n \neq k)$$

Here $\rho_n = \rho_{nn}$, H_0 is the Hamiltonian of a paramagnetic i in the stationary magnetic field $\boldsymbol{B}$, $H_1(t)$ the energy of int action with the external ac-field, γ_{nk} are the coherence dec rates, and the rate of variation of the external field is su posed to be much less than $\omega_{nk} = (E_n - E_k)/\hbar$. Off-diagon elements of the relaxation matrix W_{kn}^{SL} $(n \neq k)$ are transiti probabilities induced by the electron–phonon interaction. F one-phonon transitions, $W_{nk}^{\mathrm{SL}} = w_{nk}[(n(\omega_{nk}) + \Theta(\omega_{kn})]$ $(n$ $k)$; $W_{nn}^{\mathrm{SL}} = -\sum_{k\neq n} W_{kn}^{\mathrm{SL}}$, where w_{nk} is the probability of t spontaneous transition, $n(\omega_{nk})$ the phonon occupation numb Θ is the step function.

In the case of a finite concentration of paramagnetic ion interactions between ions induce energy exchange (cros relaxation), and the master Eq. (1) contains additional nonline terms [5,6]:

$$\dot{\rho}_n = \sum_m W_{nm}^{\mathrm{SL}} \rho_m + R_n,$$

* Corresponding author. Tel.: +7 8432362537; fax: +7 8432387418.
E-mail address: boris.malkin@ksu.ru (B.Z. Malkin).

0925-8388/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2007.04.193